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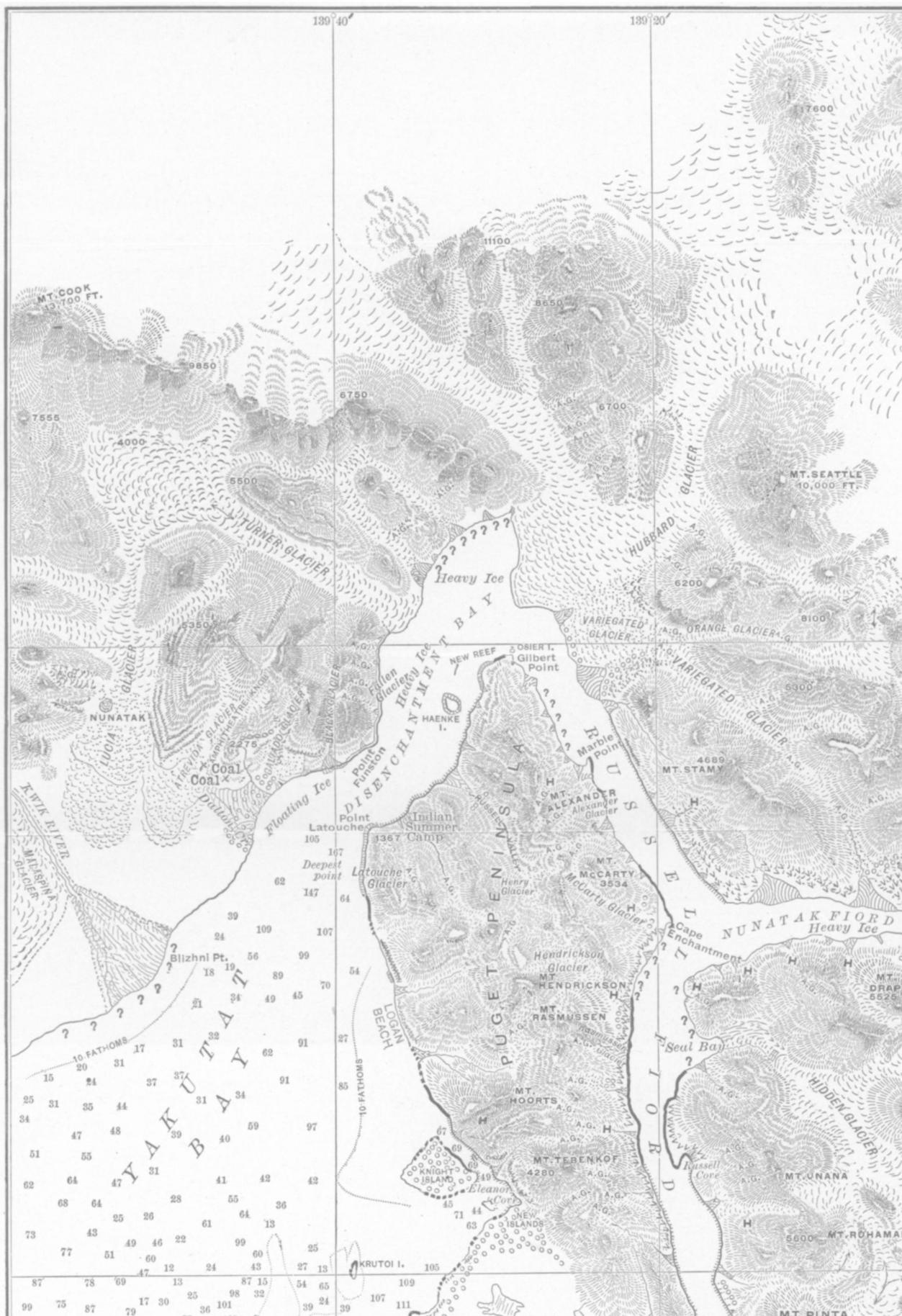
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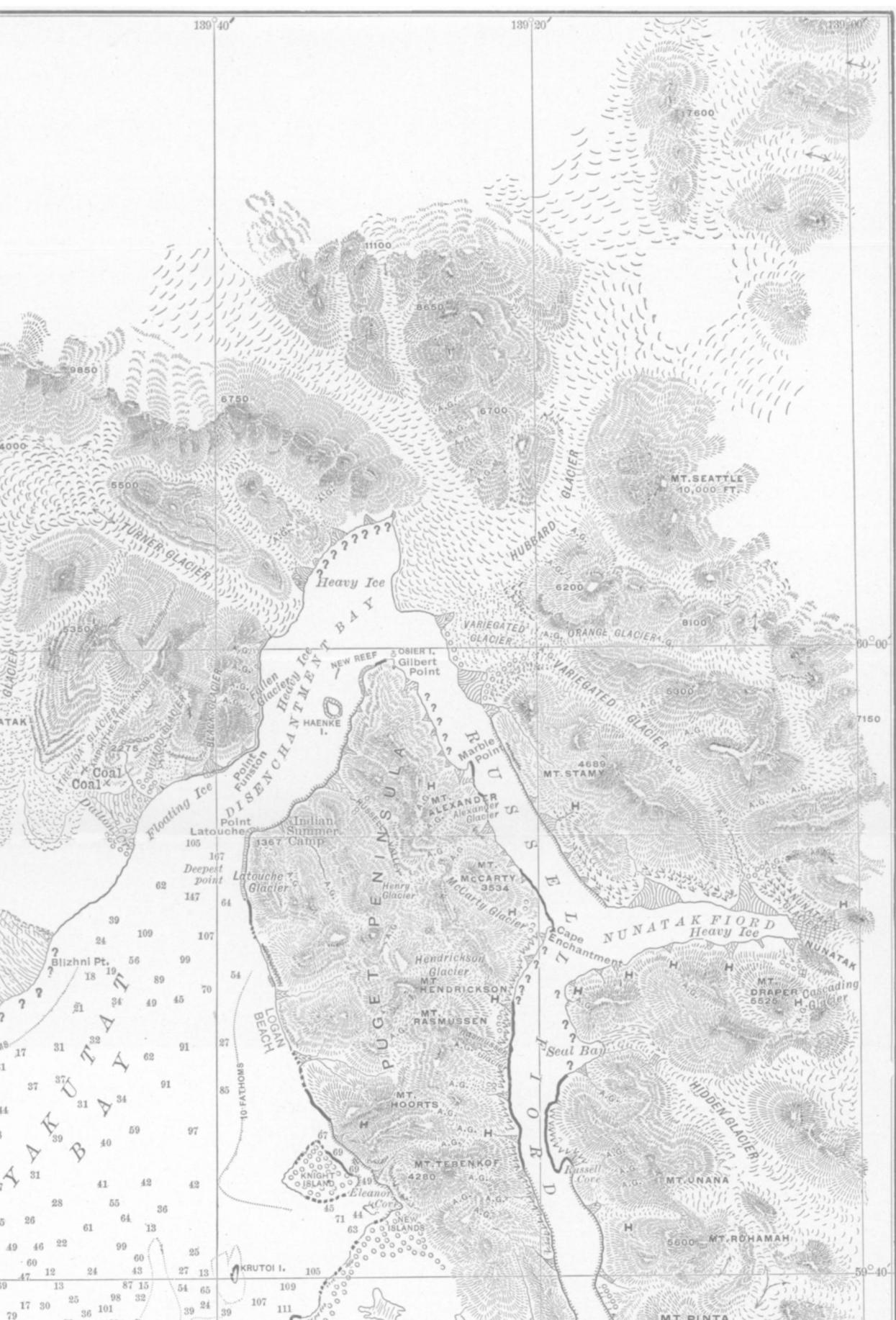
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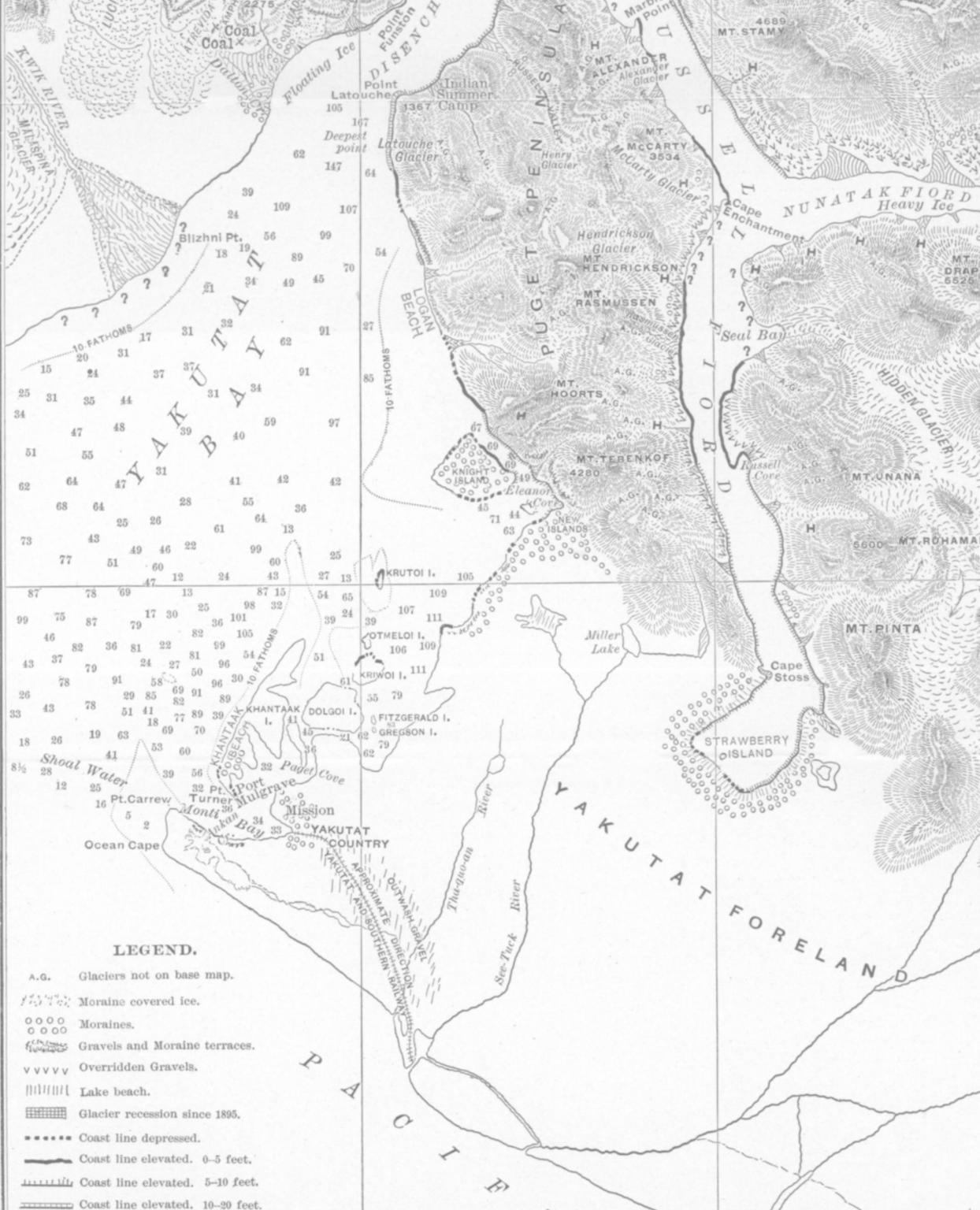
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## Glaciers of Yakutat Bay

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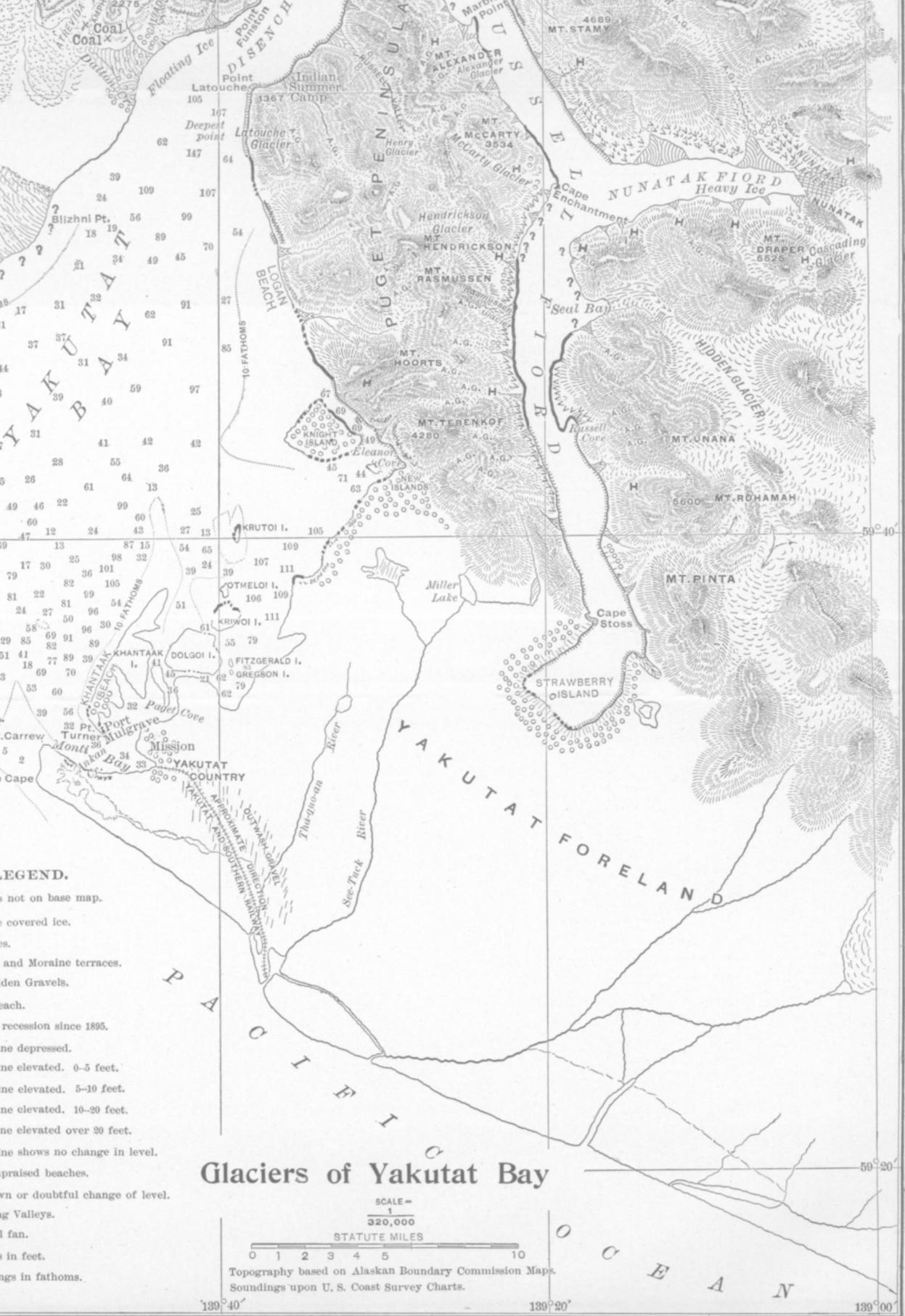
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Topography based on Alaskan Boundary Commission Maps.  
Soundings upon U.S. Coast Survey Charts.

140° 00'

139° 40'

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BULLETIN  
OF THE  
AMERICAN GEOGRAPHICAL SOCIETY.

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GLACIERS AND GLACIATION OF YAKUTAT BAY,  
ALASKA.\*

BY

RALPH S. TARR AND LAWRENCE MARTIN.

LOCATION.—The Yakutat Bay Inlet penetrates the St. Elias chain just south of Mt. St. Elias, forming the only considerable indentation on the long stretch of regular coast-line between Cross Sound and Controller Bay. The inlet is in the form of a bent arm, the broad part where it leaves the ocean being called Yakutat Bay, the narrow portion near the elbow Disenchantment Bay; the remainder Russell Fiord, from which there is one large arm, Nunatak Fiord. For the greater part of its length the inlet is mountain-walled; but part of the shores of outer Yakutat Bay and the head of Russell Fiord are a low moraine and outwash gravel plain, formed during a former stage of greater glaciation. This plain is called the Yakutat fore-land.

EXISTING GLACIERS.

GENERAL DESCRIPTION.—Four large glaciers descend from the mountains surrounding the inlet, three of them—the Turner, Hubbard, and Nunatak—entering the sea. The fourth, the Hidden Glacier, descends nearly to sea-level, but terminates at the head of a gravel plain built in Seal Bay by outwash gravels from the glacier. Besides these great glaciers there are two or three score more within sight of the fiord, some of them tributary to the large glaciers, others independent. Of the latter some descend nearly to the sea, others

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\* The observations outlined below were obtained in connection with a geological study of the Yakutat Bay region by a United States Geological Survey party, in 1905, in charge of the senior author. A grant of money from the American Geographical Society made it possible to add the junior author to the party, as special assistant in physiography. Acknowledgments are due to B. S. Butler, the other member of the party, for assistance in this work.

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occur at the heads of valleys, and still others in the mountain cirques. Many of them have moderate slope, and there is every gradation from these to glaciers which occupy valleys having such a steep slope as to render the glacier ice unstable. In fact, one of these slid out of its valley while we were in the fiord.

When Russell viewed the country north of Mt. St. Elias he found it to be "a vast snow-covered region" with hundreds of mountain peaks projecting through it—"a land of nunataks." The maps of the Canadian Boundary Commission bring this feature out clearly. The region northwest, northeast, east, and southeast of Yakutat Bay is partly drowned in ice-fields, all the valleys being ice-filled. The large glaciers are outlets of this interior ice drainage and quite different from ordinary valley glaciers, like those of Puget Peninsula\* and the smaller glaciers along the bay, which are merely outlets of local ice basins. It is possible to go over ice divides from one large glacier to another, and in several instances the prospectors have made use of these glacial highways. It is an inviting and virgin field for geographical exploration.

All the larger glaciers were studied as fully as time permitted, and a number of the smaller ones were made the subject of some investigation. They reveal many interesting features, some of which will be described under the succeeding headings. The four large glaciers were studied and described by Prof. Russell, and later by Dr. Gilbert,† to whose photographs, descriptions, and interpretations we owe much.

THE HUBBARD GLACIER.—This great glacier, one of the largest in Alaska, descends from an unknown source far back in the St. Elias range, and advances boldly into the bend of the fiord, its icy cape forming one of the points dividing Disenchantment Bay from Russell Fiord. For about four miles it presents a jagged ice-cliff rising from 200 to 300 feet above the fiord and almost constantly discharging icebergs from its face. These discharges send out great ring waves, which spread to the neighbouring shores, causing a succession of breakers far down Disenchantment Bay, even beyond Haenke Island. The procession of icebergs, reinforced by a lesser supply from the Turner and Nunatak Glaciers, passes down Disenchantment Bay, and thence down the west shore of Yakutat Bay, often forming such dense bands as to seriously interfere with navigation. So much ice melts or goes ashore that little reaches the

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\* This name is proposed for the peninsula between Russell Fiord and Yakutat and Disenchantment Bays. Puget, one of the earliest explorers of this region, certainly desires to have his name applied to some part of it.

† Harriman Alaska Expedition, Vol. III, GLACIERS, 1904, pp. 45-70.



FIG. 1.—LOOKING SOUTHWESTWARD ALONG SOUTHEAST MARGIN OF HUBBARD GLACIER, SHOWING VALLEY BETWEEN IT AND VARIEGATED GLACIER, WITH MARGINAL LAKES ENCLOSED. SHOWS THE SWINGING OF THE HUBBARD MORaine WESTWARD, NEAR THE ICE TERMINUS.



FIG. 2.—VARIEGATED GLACIER FROM ELEVATION OF 1,000 FEET ON GILBERT POINT. TWO GLACIERS DESCEND FROM THE MOUNTAINS AND UNITE TO FORM A MORaine-COVERED, APPROXIMATELY STAGNANT, BULB-SHAPED PIEDMONT AREA.  
(SEE FIGS. 3, 4 AND 5.)

Pacific. Some of the ice is swirled by tides and currents into Russell Fiord, and this ice, added to the supply from the Nunatak Glacier, dots the surface of Russell Fiord as far as Cape Enchantment. South of this cape icebergs become rapidly less numerous, but scattered bergs were found nearly to the head of the bay.

The Hubbard Glacier is made by the union of two large arms to which numerous smaller glaciers are tributary. Both are greatly crevassed, as is the glacier below their union; and both are nearly free from moraines except at their margins. The western arm bears a medial moraine, and the lateral moraine of the north side of the eastern arm comes down to the sea nearly parallel to it. In consequence of the general absence of moraine the glacier front is, on the whole, a clean, beautiful ice-cliff except at the very margins, where it is blackened by morainic débris.

Both arms of the glacier have an abrupt descent where they emerge from their mountain valleys, thus introducing a step in the otherwise gentle slope of the ice. Apparently, if the ice were removed from this valley there would be revealed here an upward step from the main valley into each of these tributaries. Of the two glacier arms the eastern is the larger; and the direction of the ice-currents, as indicated by the medial moraines, is dominated by this arm below its union with the western tributary.

THE VARIEGATED GLACIER.—Adjoining the Hubbard Glacier on the south is an extensive moraine-covered area fed by two rather small glaciers (Fig. 2). The southern arm heads in a low divide (Fig. 3), from which another glacier descends eastward towards Nunatak Fiord; the northern arm heads among the mountains, and descends in a deep, narrow, sinuous mountain valley. The two, uniting, form a bulb-like expansion which is almost completely covered with moraine, and which in large part is nearly, if not quite, stagnant. In one place this piedmont bulb coalesces with the moraine-covered margin of the Hubbard Glacier; but for much of the distance it is entirely separated from the Hubbard Glacier (Fig. 1); and it is apparently not influenced in any way by the Hubbard Glacier, or the Hubbard by it. In consequence of this it has been deemed proper to consider this ice-mass a separate glacier and not a part of the Hubbard. Because of its vari-coloured moraines it is named the Variegated Glacier. It nowhere presents an ice-cliff to the sea.

A remarkable feature of this glacier is the presence upon it of a series of roughly concentric moraines, differing from one another in colour because of the predominance of rocks of different colours

in the several moraines. One band is black because of the abundance of black hornblendic gneiss; another gray because of the presence of a large percentage of white granite boulders; a third is purple by reason of the great quantity of purple gneiss boulders; and a fourth is orange-coloured because of a bright orange rust on a gneiss which predominates in it (Figs. 3 and 4). Because of their strong colour and their marked height these moraines are prominent features even at a distance of five or six miles. They are not terminal moraines, but bands of débris on the ice surface, brought into strong relief by ablation. The highest of them rise over 100 feet above the base (Fig. 3), but all are found to have ice in them at the depth of a few feet. This ice is melting out so rapidly that there is little vegetation on the moraine because of its frequent slipping. If all the ice should melt out from beneath the moraines there would still be left a series of ridges differing prominently in colour, but of no great height.

The source of these vari-coloured moraines is evidently the cliffs enclosing the two contributing glaciers, where each of the rocks forming the moraines occurs. That the material is not basal in origin is proved by its highly angular character, which is that of lateral moraines and not of the ground moraine. Since the ice of the contributing glaciers is not now in even contact with some of the cliffs from which the rocks must have been derived, notably the black hornblendic gneiss, it is believed that these moraines were brought down during a higher stage of the ice, when the two glaciers pushed their bulb-shaped terminus out into the fiord. This moraine-covered ice is now melting away, but some ice still exists under the moraine almost down to the shores of the fiord. Under the moraine cover the ice is disappearing very slowly, and no difference is distinguishable in the photograph taken by Dr. Gilbert in 1899 from our view in 1905.

In the midst of this moraine is an extensive depression about 95 feet above sea-level and 150 feet below the level of the moraine-covered ice which separates it from the sea (Fig. 5). Into this depression pours water from each of the tributaries of the Variegated Glacier. The gravels which these streams bear are in part built into a gravel plain in the midst of the moraine; but some escapes through a gorge in the moraine-covered ice, through which the united glacial streams flow to the sea. That this outwash gravel plain is underlain by ice is proved by the existence of pits at present being formed on its floor by the slumping due to melting out of the ice-floor. This depression apparently represents an area of ice relatively clear of moraine, and consequently much more rapidly



FIG. 3.—THE ORANGE GLACIER (ON THE LEFT), WITH THE INNERMOST OF THE CONCENTRIC MORAINES. THE THROUGH-GLACIER ARM OF THE VARIEGATED GLACIER SHOWS ON THE RIGHT. VIEW LOOKS NORTHEASTWARD, AT ELEVATION OF 870 FEET. CAMERA STANDS ON CREST OF MORAINE BENEATH WHICH IS ICE.

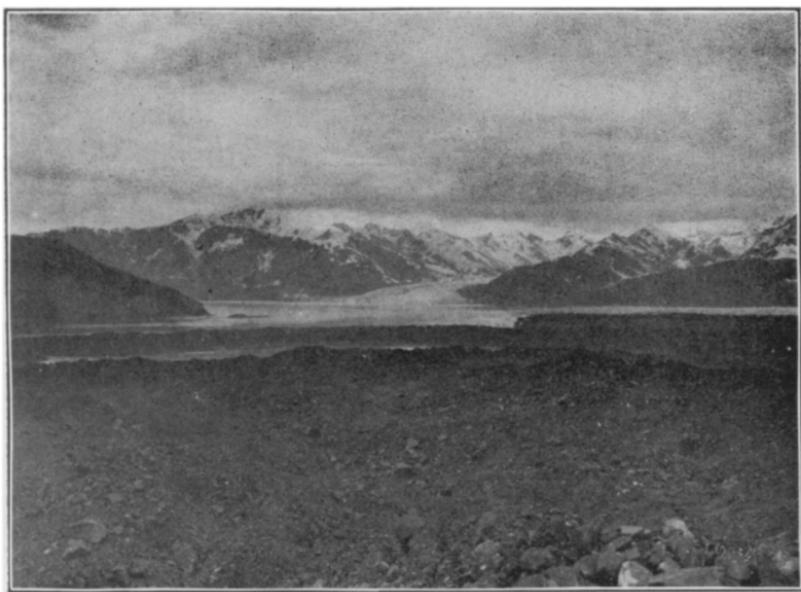


FIG. 4.—MORAINE-COVERED, BULB-SHAPED TERMINUS OF VARIEGATED GLACIER, FROM ELEVATION OF 850 FEET, LOOKING SOUTHWESTWARD. TURNER GLACIER IN BACKGROUND. THE CONCENTRIC MORAINES ON THE GLACIER, AND THE GRAVEL PLAIN BETWEEN THEM ARE BROUGHT OUT.

lowered by ablation. On either side the moraine-covered ice rises abruptly 100 feet or more. There is represented here the rather anomalous condition of glacial streams emerging, not from the ice terminus, but two or three miles from it, flowing over and through the glacier, and building an outwash gravel plain upon it.

**THE TURNER GLACIER.**—This glacier, approximately a mile wide in its mountain valley, spreads out in a flat, fan-shaped ice-foot on emerging from its valley, and by this means more than doubles its width at its terminus in Disenchantment Bay. Like the two arms of the Hubbard Glacier, the Turner descends by a step from its mountain valley (Fig. 6); and this is interpreted as indicating that the Turner Glacier valley is hanging well above the level of the main valley occupied by Disenchantment Bay. The glacier is greatly crevassed, and is evidently actively advancing, since there is frequent discharge of icebergs along its sea cliff, which, by Locke level, was found to rise about 200 feet above the water. Along each margin there is a narrow band of lateral moraine, which at the front rests on the land, forming a dirt-laden toe projecting from the ice-foot. There is also a medial moraine.

**THE NUNATAK GLACIER.**—A few miles above the terminus two large arms unite to form this tidal glacier (Fig. 8). The southern arm heads in a broad, low divide—a characteristic feature of many glaciers of this region. Instead of being formed by the union of a series of tributaries fed from lofty cirques and snow fields, this glacier, like many others in the region, rises by moderate grade to a flat ice divide, filling a broad valley from side to side and sending glaciers down from the divide in both directions. Tributaries enter from the valleys of the enclosing mountains, but at least a part of the glacier supply comes from the accumulation on the broad, flat divide which rises well above the snow-line. The grade is so slight across the divide that several years ago the Nunatak Glacier was used as a highway by large numbers of prospectors, who crossed over this ice divide into the Alsek valley. For this condition of glaciers, extending up to broad ice divides, and continuous with similar glaciers extending in the other direction, the name *Through Glaciers* is proposed (Figs. 7 and 8).

About two miles back from its terminus the Nunatak Glacier divides into two distributaries, or tongues, the smaller ending in a land valley, the larger, about a mile wide, ending in the fiord, in an ice-cliff (Fig. 7), from which there is incessant discharge of bergs. These two tongues are separated by a rock hill rising 1,440 feet (by barometer) above the fiord. When this glacier was first seen by

Russell in 1891 its two arms completely encircled this hill, whence the name Nunatak Glacier. In 1905 the two ice-tongues did not more than half surround the nunatak.\*

Just south of the terminus of the land end of the Nunatak Glacier there is a pronounced hanging valley, from which a glacier emerges, and, descending over the lip of the hanging valley, rests on a series of ledges formed by lateral sculpturing of the cliff face during a recent stage of higher ice (Fig. 9). This hanging glacier terminus, with its crevassed steps, suggested to Dr. Gilbert the very descriptive name of Cascading Glacier. On the north wall of the fiord, just below the terminus of the sea end of Nunatak Glacier, is another hanging valley occupied by a glacier; but this one does not pass beyond the edge of the hanging valley, and its terminus is covered with moraine (Figs. 14 and 15).

**THE HIDDEN GLACIER.**—This large glacier, about a mile wide, descends with moderate slope from a broad, flat ice divide to within a little more than two miles from the sea. Its surface is only slightly crevassed, and it is very clean and free from débris. Even the lateral moraines have but moderate development. From its front emerge two glacial streams, the larger, a rushing torrent, coming from the south side. These streams are building an outwash gravel plain in the valley (Fig. 10). This plain fills the valley bottom from the ice terminus, where its elevation is 150 feet, to the sea at the head of Seal Bay, forming a gently-sloping valley-bottom plain over which the glacial streams flow in braided courses. The upper part of this plain occupies the site of the ice terminus when photographed by Dr. Gilbert in 1899;† and, near the glacier, ice is visible beneath the gravel plain. That the ice underlies the gravel plain for at least a mile below the present terminus of the visible glacier is proved by the presence on this plain of numerous pits and kettles from a few feet to 250 feet in longer diameter (Fig. 11) and 5 to 15 feet deep. These kettles have steep, angular gravel margins, which were in process of development during our visit, being surrounded by a cracked, faulted, and fissured area, due to the withdrawal of support from beneath. Some of the kettles were dry, but many contained water, and from some clear, cold water flowed away, to form minor streams on the gravel plain.

As has been shown by Dr. Gilbert, who first described this plain, the presence of ice beneath the gravels is here giving rise to a *pitted plain*—a phenomenon with which glacial geologists are fa-

\* For this hill the name Gannett Nunatak is proposed, after Henry Gannett, whose maps of the Nunatak and other glaciers show the position of the ice-fronts in 1899.

† See Harriman Alaska Expedition, Vol. III, Plate VI, opposite p. 56. Compare with Fig. 15.



FIG. 5.—OUTWASH GRAVEL PLAIN BETWEEN MORAINE-COVERED ICE RIDGES, LOWER BULB-SHAPED END OF VARIEGATED GLACIER. VIEW TOWARD SOUTHWEST, FROM MORAINE-COVERED ICE, ACROSS GRAVEL FLAT TO MORAINE-COVERED ICE NEARER THE SEA, ENCLOSING THE GRAVEL FLAT IN A SWEEPING CURVE, CONCAVE TOWARDS THE GLACIER.

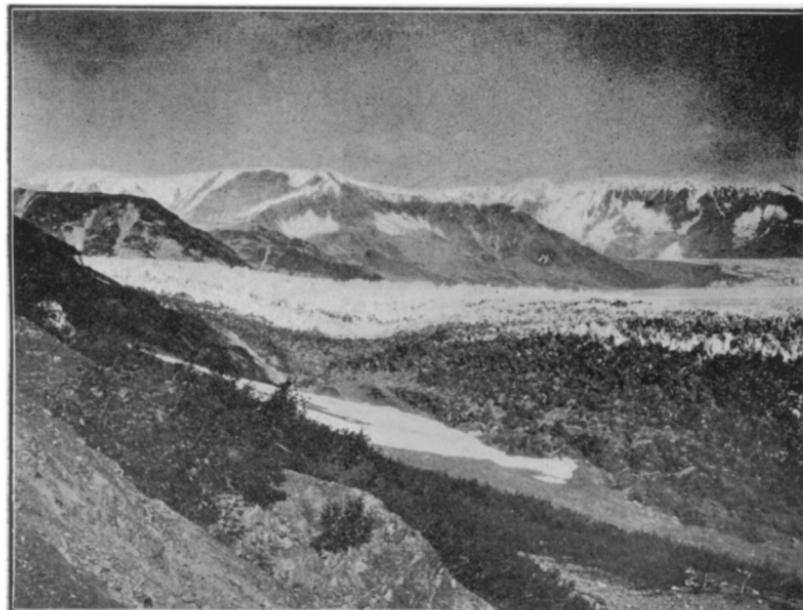


FIG. 6.—PROFILE OF LOWER END OF TURNER GLACIER FROM ELEVATION OF 525 FEET. VIEW LOOKS NORTH.

miliar among the deposits of continental glaciers. That a large mass of ice can be left in front of a receding glacier and be then protected from rapid melting by a veneer of outwash gravels has been inferred from a study of glacial phenomena; but here the process is actually visible. Among the interesting phenomena presented by this incipient pitted plain is the presence of ice directly connected with a living glacier yet not moved perceptibly by it. That the connection is complete is capable of proof by direct observation; and that the connection does not involve a marked forward thrust is proved by the undisturbed surface of the overlying gravel plain. Evidently the glacier terminus is itself nearly, if not quite, stagnant.

On the northern margin of the Hidden Glacier the ice is resting on a gravel deposit of earlier date, which it has overridden without removal (Fig. 12). This observation supplements that of Dr. Gilbert, who, in describing the same gravel deposit a half mile farther down the valley, called attention to the fact that it had been overridden. The proof of such former overriding is very clear both here and in other parts of the fiord, as will be shown under another heading. Thus the Hidden Glacier presents two interesting phenomena of opposite character—(1) the glacier is overriding earlier gravels on the north side, and (2) in the middle of its front is itself covered by gravels derived from its own melting.

MINOR GLACIERS.—A number of the smaller glaciers were studied; but the results of these observations will not be presented in detail here. One fact of general interest is illustrated by a large number of the smaller glaciers—namely, the great areas of morainic débris upon the lower ends. This moraine frequently covers the glacier from side to side and for a distance of from one to three miles from the terminus. Very often the moraine cover completely hides the ice, so that it is impossible to fix its exact terminus. But generally, even when the ice is not visible, its presence is indicated by the large quantity of water which emerges from the moraine as springs, and by the fissuring of the moraine, due to slumping as the ice is melted out from beneath it. Such moraine cover is usually associated with stagnant or nearly stagnant ice, and its presence is evidently an important factor in retarding the melting of the ice. On such moraines alders and willows frequently grow, sometimes forming thickets. Some of the alders are from fifteen to twenty years old, but more commonly they are less than five or six years.

This abundance of moraine is due in part to the friable nature of the weak rocks of the Yakutat Series, which are readily disrupted by frost action; but moraine-covered glaciers are also found among

the crystalline rocks. Both here and in the glaciers among the weaker rocks an important cause for abundance of moraine is the form of the enclosing valleys, which have been over-deepened, and have had their sides greatly steepened by glacial erosion during a recent period of greater ice advance. This has given to the enclosing valley walls an unstable form, which yields readily to rapid weathering, and therefore tumbles great quantities of rock fragments down upon the glaciers.

THE BLACK AND GALIANO GLACIERS.—These two glaciers, on the west side near the head of Yakutat Bay, were photographed by Prof. Russell in 1890, and a comparison of the present conditions with those of 1890 reveals some astonishing facts. The Black Glacier has scarcely changed at all, and an examination of its front, with Russell's photograph in hand, from essentially the same site as that from which it was taken, showed changes of only minor degree. It still comes out to the end of its mountain valley and terminates in an abrupt ice-cliff without expansion, and is apparently in almost the exact position it occupied during Russell's visit. That it has not recently been more than 200 or 300 yards farther out is proved by the presence at that distance of a mature forest, while at a distance of 100 yards from the ice there is an alder growth with bushes from ten to fifteen years old.

Galiano Glacier, about two miles farther southwest, on the other hand, has undergone profound change. Russell's photographs show it as emerging from its mountain valley and spreading out fan-shaped on the plain between the mountains and the sea; and it still has this condition. But both Russell's description and his photographs show that this expanded, moraine-covered terminus was in 1890 covered with dense alder growth and some trees, whereas there are now no trees on it and only a few scattered alders five or six years of age. There are, however, numerous fallen trunks, and a large number of torn stumps standing upright on the face of the moraine-covered ice-front. The vegetation of Russell's day has evidently been destroyed by an advance of the ice.

Russell's photographs of this glacier reveal an extensive alluvial fan in front of it which no longer exists. In its place occur morainic hummocks through which the fan-building stream now flows, depositing its gravels among the hummocks. Concerning these facts the evidence is clear and convincing, but it has been found difficult to place upon them a satisfactory interpretation. Proper consideration of this problem would require more space than is here available. The problem is, why should two neighbouring glaciers show such differ-



FIG. 7.—NUNATAK GLACIER (SEA END) FROM THE NORTH SIDE OF THE FIORD. SHOWS THE THROUGH-GLACIER CONDITION OF THE SOUTH ARM. GANNETT NUNATAK ON THE RIGHT.

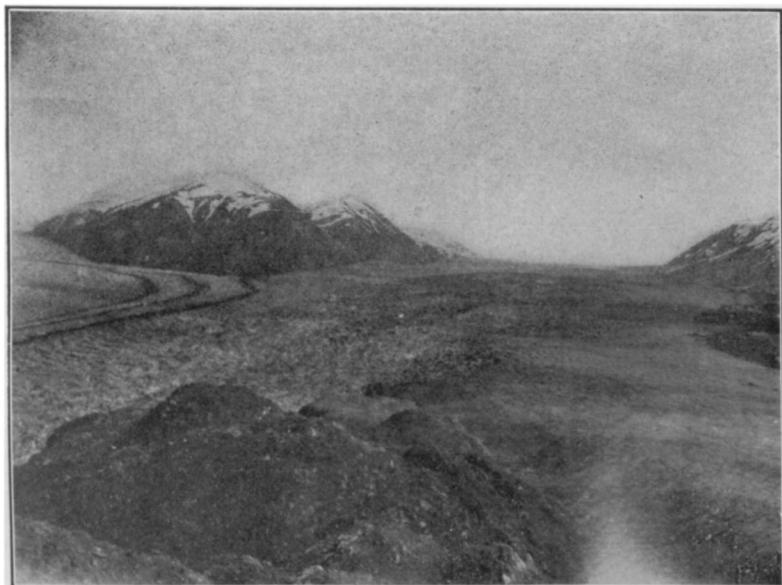


FIG. 8.—NUNATAK GLACIER FROM CREST OF GANNETT NUNATAK AT ELEVATION OF 1,400 FEET. SHOWS THROUGH-GLACIER CONDITION OF SOUTH ARM OF NUNATAK GLACIER.

ent histories in a given time? And exactly what have been the changes on and in front of the Galiano Glacier? This problem will be discussed more fully in the final report of the expedition.

**FALLEN GLACIER.**—Photographs by both Russell and Gilbert, taken respectively in 1891 and 1899 from the summit of Haenke Island, show three small hanging glaciers in steep valleys on the west side of Disenchantment Bay, south of Turner Glacier. The southernmost of these glaciers was over a mile long, and its terminus about 1,000 feet above the water. On the third day of July we photographed this glacier from the fiord nearly opposite, and this proved to be the last day in its life. The next day at ten o'clock, when we were fortunately in Russell Fiord, about fifteen miles away, we were surprised by the appearance of a series of waves which rose on the shore fifteen to twenty feet vertically, and continued for nearly half an hour. Later we found that the glacier had slid bodily out of its valley and tumbled into Disenchantment Bay, leaving only a few small remnants clinging to the valley sides.

On visiting the valley later in the season the destruction performed by the glacial avalanche was found to be extensive, and the smoothed bed of the glacier was clearly revealed. Its fall caused a series of huge waves which rose on the coast nearby to a height of 110 feet, and on the north side of Haenke Island 115 feet (by Locke level), washing up and rending willows and alders at this elevation. At the point where we had photographed the glacier on the day before its fall the wave destroyed vegetation thirty feet above high tide. The Indians report that this same glacier slid out of its valley sixty years ago and killed a hundred Indians; but fortunately the Indians had left their summer sealing camp before July 4th, 1905, and no one was on Disenchantment Bay, otherwise there would certainly have been destruction of life.

**RECENT RECESSION OF GLACIERS.**—Most of the smaller glaciers studied show abundant evidence of recent recession, and it is evident that this shrinkage is still in progress. Unfortunately, we have no means of proving the exact amount or rate of this retreat, for in most cases there have been no previous records. The evidence of marked recession is, however, clear. It is in the form of moraine-covered ice remnants in front of the present ice termini (Fig. 22), and of barren areas in front of the ice, on which in some cases even annual plants have not yet taken root (Figs. 19 and 23).

For the larger glaciers the photographs by Russell and Gilbert and the maps by Gannett give us a basis for more exact comparison, and in some cases it was found possible to relocate the

sites of the photographs taken by these observers. In the case of the Hidden Glacier the site of one of Gilbert's pictures was determined rather closely, though the exact spot could not be found.\* Both by this and by a plane-table map the amount of recession of the snout of Hidden Glacier between June 1899 and July 1905 is found to have been about a quarter of a mile.

The exact site of Gilbert's photograph of the sea end of Nunatak Glacier was located, even the stones in the foreground being identical in the two cases. These two photographs are reproduced as Figs. 13 and 14. In this case the recession between 1899 and 1905 is not far from a mile. The land end of the Nunatak Glacier has receded between an eighth and a quarter of a mile since 1899, and the Cascading Glacier has diminished perceptibly.

RECENT ADVANCE OF TURNER AND HUBBARD GLACIERS.—Our photographs of the Turner and Hubbard Glaciers, taken from the sites of the photographs by Russell and Gilbert, were unfortunately not very successful, and our plane-table map does not definitely prove any change in the ice-front of these two glaciers. To show the present condition, marks were made on these earlier photographs while occupying the sites from which they were taken, and these show clearly a change in both glaciers. A comparison of our photographs with those of Russell and Gilbert shows fairly well the changes which we detected in the field.

In both of the earlier pictures the medial moraine in the ice-foot near the middle of Turner Glacier appears to turn northeastward; but in 1905 this turn is gone, and the much-shortened medial moraine advances straight into the fiord. This is taken as an indication that the sea front of Turner Glacier was in 1905 several hundred yards farther back than in either 1891 or 1899. This recession may possibly be related in origin to the violent earthquake of September, 1899, which is known to have profoundly affected the Muir Glacier, and whose effects in this fiord were stupendous, as will be shown in other papers. As compared with Russell's photograph of 1891, the two ends (north and south) of Turner Glacier front had in 1905 receded perceptibly; but as compared with Gilbert's photograph of 1899, the two ends have advanced slightly. The evidence, therefore, indicates for this glacier a general recession between 1891 and 1899 and a slight advance on the two ends between 1899 and 1905, but a recession in the centre.

A photograph taken in 1899 by Gilbert, on the south side of Hubbard Glacier, looking along the front of the ice-cliff, was dupli-

\* See Fig. 15 and compare with Gilbert's picture in Harriman Alaska Expedition, Vol. III, Plate VI.



FIG. 9.—CASCADING GLACIER, JULY 24, 1905, FROM SOUTH SLOPE OF GANNETT NUNATAK, LOOKING SOUTHWARD. SHOWS STRONG GROOVING OF VALLEY SIDE, AND CASCADING GLACIER ISSUING FROM ITS HANGING VALLEY AND DESCENDING THE TERRACES. THE VERTICAL BANDS ARE THE RESULT OF STREAMS FLOWING DOWN THE CLIFF SIDE FROM THE GLACIER.

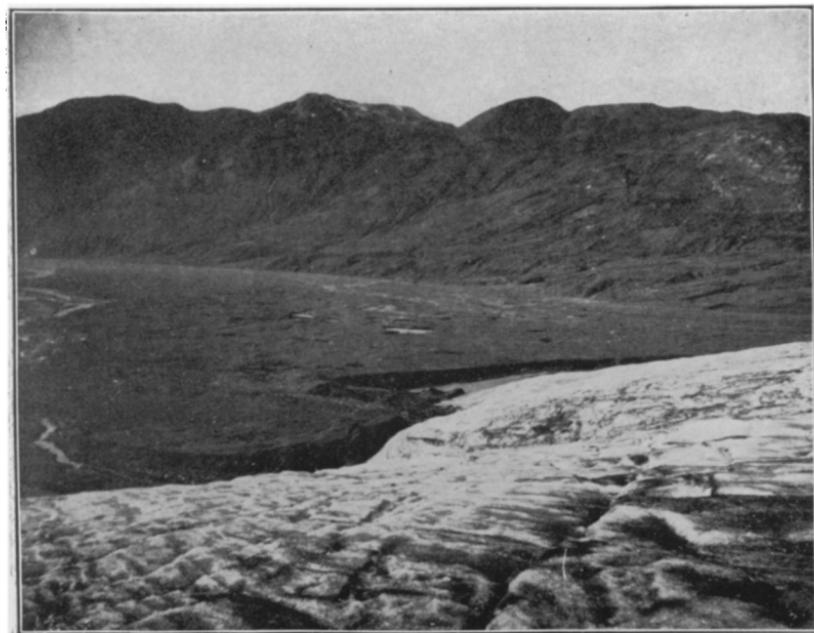


FIG. 10.—PITTED OUTWASH PLAIN BELOW END OF HIDDEN GLACIER. VIEW LOOKS NORTHWESTWARD. CAMERA STANDS ON HIDDEN GLACIER. GLACIATED TOPOGRAPHY AND ABSENCE OF VEGETATION ARE NOTABLE. VIEW TAKEN JULY 25, 1905.

cated as nearly as possible in 1905; but Gilbert's exact site could not be found. From this station it appears that the ice has receded, but the correctness of this conclusion is rendered uncertain because of doubt as to the exact location of Gilbert's picture. We could not, however, find any spot as near the ice as Gilbert's picture, and with the proper relation of beach to ice, where anything but recession could be inferred. On the other hand, from the Gilbert and Russell sites on Haenke Island, and from Gilbert's site on Gilbert Point\* above Osier Island, it is evident that the northwest half of Hubbard Glacier has advanced between 1899 and 1905, though the exact amount cannot be stated. The evidence of this advance is that the northwestern end of the glacier on the land is farther out, and the medial moraine of the western tributary of the Hubbard Glacier now bends farther southward than in either 1891 or 1899. This suggests the possibility that the western arm of the Hubbard is advancing and the eastern receding.

One of our Indians, who hunts seal in the bay each year, was very confident that the Hubbard Glacier has been advancing for the last ten or twelve years; but our plane-table map, as compared with that of Gannett, does not support this view. However, with a short base-line, and with the great distance to the various points on the glaciers, small changes might not appear. Our study of the photographs made by Gilbert and Russell convinced us that there has been an advance of the northwestern part of the Hubbard Glacier, both as compared with the photographs of 1891 and with those of 1899. Our photographs will be published in the final report, where this subject is more fully discussed.

#### FORMER EXTENSION OF GLACIERS.

That the glaciers of this region have at one time been much more extensive, and in fact have occupied the entire inlet, is clearly demonstrated by three important lines of evidence: (1) The Yakutat foreland; (2) the presence of high-level moraines on the mountain slopes; and (3) the evidence of profound glacial erosion. Each of these lines of evidence will be briefly considered.

These former greater ice streams will be spoken of as the Yakutat Bay Glacier and the Russell Fiord Glacier.

THE YAKUTAT FORELAND.—This broad foreland is so densely wooded over part of its area, especially near the shores, that its exploration is difficult. We entered it a short distance at several points, and at Yakutat went out upon it for about ten miles to the

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\* Named for Dr. G. K. Gilbert.

terminus of the Yakutat and Southern Railway. From the slopes of Mt. Tebenkof we gained, also, a good bird's-eye view of the foreland. From these examinations it was found that the foreland consists of two quite different classes of deposits. Near the shores of Yakutat Bay and south of the head of Russell Fiord it is distinctly morainic, with hummocks and kettles, some of them occupied by lakes and swamps. In this part of the foreland there are quantities of large crystalline boulders, evidently brought from far back in the St. Elias chain. Fringing these moraines to the south and east is a level plain, or prairie, free from forest over a great part of its area because the drainage is too slack for tree growth. This plain, sloping gently seaward, is made of outwash gravels, evidently of the same origin and general character as those now building along the margin of the Malaspina Glacier.

The evidence from the foreland points to the presence of moraine-building ice, filling both Russell Fiord to its head and Yakutat Bay clear to Yakutat, and building up the area intervening between the ends of the two glaciers with outwash gravels from each of the great glaciers. That during this expansion of the glaciers ice extended out to the present mouth of Yakutat Bay is indicated by the soundings, which show a general though irregular rise in the bottom of the bay from its head, where it is 1,000 feet deep, to its mouth, where the water is everywhere shallow, being nowhere over 100 feet deep and over most of the distance from 50 to 75 feet deep. This shoal forms a definite, narrow ridge completely across the mouth of Yakutat Bay. Just inside of the ridge the water rapidly deepens.

Exactly what relation this expanded Yakutat Bay Glacier bore to the Malaspina is not now clear. That the two must have coalesced is evident; and that the Malaspina Glacier dominated in the lower part of the bay is indicated by the west-facing, irregular coast of the eastern side of the bay and its series of islands. If the sea was then at its present level there must have been a continuous ice-cliff across the site of the present mouth of Yakutat Bay, and far to the westward along the front of the present Malaspina. Whether the Yakutat Foreland was begun as a deposit in the sea is not now certain; but it is clear that it was finished above sea-level, and apparently approximately at the present level. This conclusion is based upon the fact that so much of its surface is alluvial fan, which could have been made only above sea-level. That before the advance of the ice the foreland was higher than now is proved by the presence of submerged forests on the beach beneath the gravels of the foreland at the head of Russell Fiord.

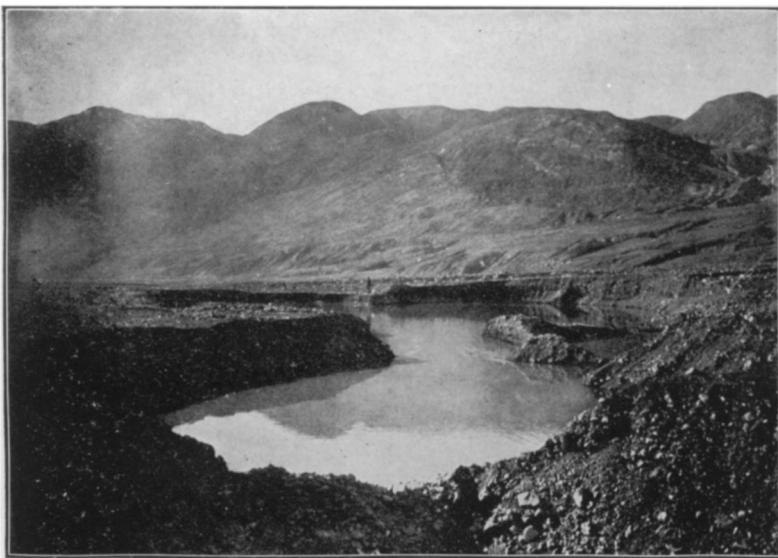


FIG. 11.—KETTLE IN OUTWASH GRAVEL PLAIN IN FRONT OF HIDDEN GLACIER, CAUSED BY MELTING OUT OF ICE BENEATH THE GRAVEL. OVERRIDDEN, HIGHER LEVEL GRAVELS SHOWN ON THE RIGHT, NEAR MOUNTAIN BASE. THE ICE HAS LEFT THE VALLEY SO RECENTLY THAT VEGETATION HAS NOT YET OCCUPIED THE GRAVELS.



FIG. 12.—TERMINUS OF HIDDEN GLACIER, JULY 30, 1905, LOOKING SOUTHWARD. SHOWS ICE RESTING ON GRAVELS WHICH, FARTHER DOWN THE VALLEY, ARE DISTINCTLY OVERRIDDEN, ICE-ERODED AND MORAINE-VENEERED. IN THE MIDDLE OF THE PICTURE, NEAR THE MORAINE-VENEERED ICE MOUNDS, THE SNOOT OF THE GLACIER DESCENDS BENEATH THE OUTWASH GRAVELS. (FIG. 10.)

An interesting record of the termination of the expanded Russell Fiord Glacier is preserved in the fist-shaped expansion, outside the mountains, that constitutes the head of the inlet. Evidently the Russell Fiord Glacier had a bulb terminal where released from the confining walls of the mountain fiord, and water now occupies the area formerly filled with ice at the stage of the glacier's maximum extension.

**HIGH-LEVEL MORAINES.**—Moraine deposits and foreign rock fragments occur at various points on the mountainous slopes of the fiord, proving the former presence of ice at these elevations. At four points we determined as carefully as possible, by the use of the aneroid barometer, the elevation to which the ice formerly reached, being careful to select places where the complication of local valley glaciation could not enter.

The first of these was on the ridge west of Cape Enchantment, which rises over 3,000 feet above Russell Fiord. Here excellent moraine occurs up to 1,350 feet, and crystalline rocks, undoubtedly brought from outside the peninsula, at 2,000 feet. Glacial scratches were observed at an elevation of 2,700 feet; but since above 2,000 feet there were no rocks that could be proved to be foreign this is taken as the elevation to which the ice-flood rose at that point.

The second point selected was on the ridge south of Point La Touche at the entrance to Disenchantment Bay. Here an excellent moraine occurs at an elevation of 1,750 feet, and foreign boulders at 1,920 feet. In the bay a mile or two west of this there is a sounding of 167 fathoms, so that at this point, at the very head of Yakutat Bay proper, the ice was at least 2,920 feet thick.

Northwest of Point La Touche, on the west side of the head of Yakutat Bay, the third point examined, there is a perfect moraine terrace which has an elevation of 1,900 feet where developed on the mountain side above the Galiano Glacier, but descends to 1,675 feet in two or three miles toward the southwest—that is, toward the Malaspina Glacier.

This height of the ice would permit the Yakutat Bay Glacier, extending out of Disenchantment Bay, to pass through some of the low divides of Puget peninsula to join the Russell Fiord Glacier; and it is probable, also, that during this higher stage of the ice the glacier streamed across the divide between the Hidden and Nunatak valleys and the Alsek River valley. The ice-divides at the present time are put down on the Boundary Commission map as 3,000 feet, and this is, of course, much higher than the rock-divide. Moreover, the elevation of the ice in Russell Fiord (2,000 feet) is too far

down the fiord to represent its maximum elevation. In view of these facts, it seems probable that the ice currents readily passed across these low divides.

The fourth point where the elevation of the ice in its flood stage was measured is on the southwestern slope of Mt. Tebenkof, just east of Knight Island. Here a pronounced moraine terrace occurs at an elevation of 800 feet, and foreign fragments were found up to 1,060 feet. This point is directly above the Yakutat Foreland and about fifteen miles from the outermost moraine of the foreland near Yakutat.

GLACIAL EROSION.—The evidence of profound glacial erosion in this fiord is clear and convincing. On the east shore of Yakutat Bay, where the valley broadens rapidly, this evidence is not very strong; and near the head of Russell Fiord, toward the end of the tongue which filled that valley, so far as can be judged from the character of the valley sides, there was evidently little glacial erosion. But in Disenchantment Bay, most of Russell Fiord, Nunatak Fiord, and many minor valleys, the evidence of ice erosion is of the most definite character. Its clearness is rendered all the more striking because of the almost complete absence of vegetation, and the general thinness of drift (Figs. 15 and 16).

One is prepared for a belief in vigorous ice erosion by the prominence of striated rock surfaces and *roches moutonnées* forms on the fiord walls. This erosion often assumes the form of a distinct grooving, by which the valley walls are sculptured nearly horizontally into terrace-like steps descending gently in the direction of ice motion. This sculpturing is at times coincident with differences in rock texture, but is often independent of it. The photograph of the Cascading Glacier (Fig. 9) well illustrates this type of sculpturing. There is terrace above terrace carved in the rock wall of Nunatak Fiord when the greater glacier flowed out of it at the time of a higher stand of the ice. The Cascading Glacier descends from terrace to terrace, with direction of flow at right angles to that of the former ice-tongue whose groovings it has been incompetent to destroy. So recent has been the last stage in this erosion of the Nunatak valley that near the glaciers the rock surfaces a thousand feet above the fiord are smoothed and striated, and glisten in the sun as their polished faces reflect the sunlight.

Where the rocks are fairly firm, but much jointed, notably in the granite cliffs on the south shore of Nunatak Fiord, the evidence of plucking is very pronounced. In such places the rock cliffs are rough and hackly as a whole, but in detail are found to consist of a



FIG. 13.—GILBERT'S PHOTOGRAPH OF NUNATAK GLACIER, JUNE 21, 1899. COMPARE WITH PHOTOGRAPH JULY 24, 1905. (FIG. 14.)



FIG. 14.—NUNATAK GLACIER, JULY 24, 1905. TAKEN FROM EXACT SITE OF GILBERT'S PHOTOGRAPH, JUNE 21, 1899. THE SAME BOULDERS APPEAR IN BOTH PICTURES. COMPARE WITH FIG. 13.

series of rounded, glaciated curves and angular fractures, indicative of both scouring and rending as the processes by which the valleys were broadened and deepened.

Associated with these evidences of powerful erosion are a series of wonderfully perfect hanging valleys, many of them occupied by glaciers, in some cases down to their very lips. The best of these valleys hang from 500 to 1,000 feet above the surface of the fiord water, and from their lips extend back into the mountains as broad, U-shaped troughs, themselves evidently broadened and deepened by glacial erosion. Where these deep, broad, discordant tributaries come to the very edge of the fiord wall, they end abruptly as wide-open valleys hanging high up above the main valley bottom (Fig. 17.)

The streams flowing out of them cascade down the fiord slope usually in a narrow gorge, but sometimes as a series of cascades on the very face of the fiord wall. The anomaly of such a valley—a broad, moderately-sloping upper part, and a narrow, steeply-sloping gorge below—is too well known to require further description; and the photographs (Figs. 14, 15, 17, and 18) illustrate it well.

The hanging valleys themselves often have tributary hanging valleys, proving that while the main valley was deepened more than the laterals, these were deepened more than their tributaries. In each case the valley wall below the level of the hanging valleys is straight, smooth, and steep, and this condition usually extends well above the level of the hanging valley. But in all cases where there are hanging valleys, the walls of the main valley exhibit striking evidence of glacial erosion up to a certain level, while above it the valley wall is made irregular by weathering and erosion of the type characteristic of subaerial work (Fig. 16).

In the steepened, ice-eroded lower slopes there are no spurs and no pronounced valleys, and the streams descending from the higher part of the mountain flow in numerous, closely-spaced parallel courses, usually on the very face of the valley wall, and never in other than shallow gorge valleys. The entire condition of valley slope and drainage development is immature, and totally out of harmony with the breadth and depth of the main valley, as well as with the topography above the steepened slope.

The hanging valleys are not hanging at a uniform level, nor is there any regular decrease in level noticeable down the fiord. The difference in level appears to depend in the main upon the relative power of ice erosion in the valleys. Speaking generally, the smaller the valley the higher it hangs above the main valley floor.

The resistance of the rock is another factor of importance; and it is a notable fact in this connection that the valleys hanging highest above the sides of the fiord are in the region of crystalline rocks, while those entering the fiord in the weaker Yakutat Series are hanging at much lower levels. As would be expected as a result of differential ice erosion, there is every gradation from the high hanging valleys to those with lips at or below the fiord-level; and the larger valleys admit the sea into their mouths, as in the case of Seal Bay and Nunatak Fiord. It is to be expected that these will also be found to be hanging above the fiord bottom when soundings have been made.

The proof that hanging valleys in glaciated regions are significant of ice erosion is now so well established that it is hardly necessary at this time to consider the question whether these phenomena in the Yakutat Bay region may be due to another cause than ice erosion. The facts all harmonize with the explanation of ice erosion, and are totally out of harmony with any other explanation that has so far been proposed. Even with the clear evidence presented in this region that as late as 1899 faulting has occurred along the axes of some of the valleys, the hypothesis that the hanging valley condition is the result of faulting seems absolutely untenable. It could not account for the difference in level of neighbouring hanging valleys; for the hanging tributaries of main hanging valleys whose rock lips show no signs of faulting; for the residual nunatak knobs on the sides and in the middle of the fiords; nor the flaring fiord walls.

The peculiar condition of lowered divides, common in Puget Peninsula and between Russell Fiord and the Alsek River valley, which makes possible the presence of through-glaciers in these situations, is interpreted as the result of the reduction of divides by ice erosion when the glaciers were of greater extension, and therefore able to stream across the lower divides. Such broad, transverse valleys in the midst of a rugged mountain region seem out of harmony with the rest of the topography, and with the dominant direction of drainage. Some of the lower through-valleys near the fiord, in which there is little or no ice at present, show evidence of vigorous ice-erosion; but the larger ones are still so deeply buried beneath ice that their characteristics are in large part obscured. Their lack of harmony with the erosional forms of the surrounding mountains proves that they are not wholly the result of subaerial erosion; the theory of block faulting is wholly gratuitous, and, in the case of the visible through-valleys, evidently not applicable. To the ice-erosion theory no strong objection appears, and it is therefore proposed in explanation of this phenomenon.



FIG. 15.—LOOKING SOUTHWARD ACROSS HIDDEN GLACIER VALLEY, JULY 26, 1905, SHOWING EXTREME END OF FRONT OF GLACIER ON THE LEFT. COMPARE WITH GILBERT'S PICTURE (HARRIMAN EXPEDITION, VOL. III, PL. VI) TAKEN FROM NEARLY THE SAME SITE, BUT A LITTLE FARTHER BACK. SHOWS A BROAD MOUNTAIN VALLEY TERMINATING BELOW IN A GORGE.

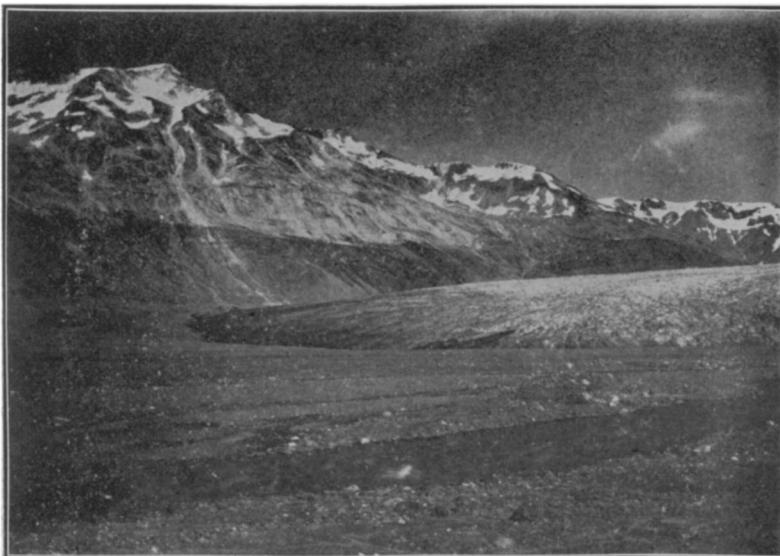


FIG. 16.—TERMINUS OF HIDDEN GLACIER, JULY 25, 1905, LOOKING NORTHEASTWARD FROM A SMALL ROCK KNOB RISING ABOVE GRAVEL PLAIN ON SOUTH SIDE OF VALLEY. SHOWS THE GRAVEL PLAIN BENEATH WHICH THE ICE DESCENDS; AND THE OLDER GRAVELS ON THE NORTH SIDE ON WHICH THE ICE NOW RESTS; ALSO STRONGLY GLACIATED TOPOGRAPHY AND ABSENCE OF VEGETATION.

## EVIDENCE OF INTERGLACIAL STAGE.

GRAVEL DEPOSITS.—Along the shores of various parts of the inlet there are gravel deposits forming low, irregular terraces. It is not certain that they are all of a single age, but they all have the same characteristic\*; and they occur all the way from the foreland up to and under some of the glaciers, notably the Hidden Glacier (Fig. 12). These gravels lie for the most part within one or two hundred feet of sea-level. Viewed at a distance, and in general, they often assume the form of terraces (Fig. 19); but when looked at in detail they are found to be undulating and not of a uniform level. Evidence is presented below to show that they are remnants of more extensive gravel deposits overridden by ice after their accumulation and partly removed by the ice-erosion. They bear no recognizable relation to existing sources of gravel, not being, for example, better developed opposite large streams. Their most typical development is in the south arm of Russell Fiord, and there they rise to a level rarely higher than 250 feet. The larger remnants occur in places where the topography suggests the possibility of weaker ice-erosion than in places where they are entirely absent.

Numerous cuts, both by streams and waves, clearly reveal the composition of the gravels in many places. They consist of cross-bedded gravels (Fig. 20) with many sand layers and occasional beds of clay, and the general dip of the layers is toward the fiord; but in many cases it is along the axis of the fiord and downward away from the ice source. The pebbles are in the main of crystalline rocks, well rounded, both of which facts indicate long transportation. They are strikingly unlike the gravels of the alluvial fans now forming near them, in which the pebbles are prevailingly of local Yakutat Series rocks and only slightly rounded. In the gravels are numerous large boulders, which must have been drifted to their place in floating ice. No animal fossils were found in the clays.

Evidently these gravels were deposited in a former, higher water body, in which ice could float boulders hundreds of pounds, and in some cases tons, in weight. Such a water body must have existed in Russell Fiord when the glaciers advanced far enough to cut it off from Disenchantment Bay, as explorations over 100 years ago indicate they did; smaller bodies of water marginal to the ice may also have existed here and in other parts of the bay. Into these water bodies glacial streams apparently built outwash gravel deposits as the ice was receding from its former maximum advance. That the

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\* There are also higher level gravels not considered here.

period of their building was not long ago is proved by the fact that the gravels are not at all disintegrated.

The period of gravel-building evidently lasted a long time, and under conditions different from the present, for in the gravels are frequently found fragments of trees in a region where no trees now grow. Most of these trunks are recumbent, but in one place they are standing where they grew (Fig. 21), buried in the gravels. In this case the trees were mature in age, their bark was preserved, and cones occurred in the clay layers in which the trees grew. One recumbent log was found in the gravel terrace of the Hidden Glacier valley, about a mile from the present ice terminus, and fully twenty miles from the nearest trees at present growing in the fiord. Our collections of wood have not yet been identified, so that it is impossible at present to tell the nature of this forest growth. It indicates, however, a long period for the formation of the gravel deposits, and the presence of conditions favouring tree growth in a region where no trees now grow. The variation of conditions which caused first coarse gravel deposition, then tree growth to maturity, then re-establishment of conditions of gravel deposition, is indicated in the present alluvial fan of Atrevida Glacier, where fluctuation of stream course and of load are to-day resulting in clay deposit in one place, and in another, the burial of a living forest, while near-by a degrading stream is uncovering a forest previously buried.

Some of the recumbent trees may have been brought to their position by the ice of the maximum advance and therefore represent a part of the preglacial forest, though this does not seem probable in view of the evidence of marked ice-erosion, which should have removed the forest and carried its remnants out to the moraine of the foreland. Moreover, the abundance of these recumbent logs seems too great for this explanation. Wave dissection is now carrying off the logs of these buried forests, and they are being built into drift-wood piles on the beaches. This is well seen at the head of the bay, where no modern forests of mature growth are reached by the waves. Consequently one's camp fires are fed by the wood of the last interglacial epoch before the present.

RE-ADVANCE OF THE ICE.—A number of facts prove that these gravels have been overridden by a glacier since their deposit. In the first place, as has been already stated, the gravels extend up to some of the glaciers, and in at least two cases the ice rests directly on the gravels. The best instance of this is at the Hidden Glacier (Fig. 12), already described; but a valley glacier on Puget peninsula just southwest of Cape Enchantment has also overridden its gravels (Fig.



FIG. 17.—HANGING VALLEY ON SOUTH SIDE OF NUNATAK FIORD. VIEW LOOKS SOUTHWARD STRONGLY GLACIATED SLOPES, RECENTLY ABANDONED BY ICE AND WITH ALMOST NO VEGETATION.



FIG. 18.—HANGING VALLEYS ON NORTH SIDE OF THE BROAD U-SHAPED GLACIATED RUSSELL VALLEY ON PUGET PENINSULA. VIEW LOOKS NORTHEASTWARD UP THE VALLEY. THE VALLEY BOTTOM IS LEVELLED BY OUTWASH GRAVELS DERIVED FROM A SMALL GLACIER AT THE HEAD OF THE VALLEY, ONE OF WHOSE RECESSIVE MORAINES APPEARS IN THE LEFT CENTER.

22); and in other cases the same condition is apparently present, though the evidence is not quite so clear.

A second proof of overriding of the gravels is the topography of the terraces. Being water-laid gravels, their constructional surface must have been a plain, determined by the water surface into which they were built and by the stream grade which was supplying the gravels. They no longer have the form of a plain, but have instead a gently-rolling surface which truncates the gravel layers. Some erosive force has removed a part of the gravels. It is not wave action, which would have cut a terrace; nor is it stream erosion, which would have cut gorges down toward a base-level. The erosive force has given the surface of the gravels an undulating outline, often broadly grooved parallel to the axis of the valley, and hence at right angles to the direction in which stream erosion would dissect them. The surface form has the appearance of an ice-eroded surface, and many miles away from the present termini of the glaciers is identical with that of the gravels of the Hidden Glacier valley, from which the ice is known to have retreated within the past six years.

Associated with this ice-erosion topography is a veneer of moraine resting on the surface of the gravels. In places the moraine is represented only by scattered boulders; but very frequently there are morainic hummocks and ridges, often enclosing kettles in which at times ponds are held (Fig. 24). Where best developed the gravel deposits have the appearance of a very thick moraine; but stream and wave cuts prove that even there the condition is really that of thick, eroded gravel beds with a thin morainic veneer. The morainic forms present some very interesting characteristics, one of the most notable being the linear disposition of assorted boulders and of moraines, resulting, evidently, from accumulation in crevasses during the final melting of the ice. There are also kame areas, and occasional eskers of small size resting on the gravels (Fig. 23).

That the gravels have been overridden by ice admits of no doubt; but the overriding did not extend the whole length of the fiord. In the southern half of the south arm of Russell Fiord the gravels have a level surface up to an elevation of about 140 feet, and on it there was found no evidence of overriding either in the form of ice-eroded surface or of moraine veneer. Above the level of 140 feet the surface is of a pronounced moraine. It is therefore inferred that the re-advance of the ice extended about half way to the head of the southeastern arm of Russell Fiord, and that the waves of an ice-dammed lake, held up in the southern part of the fiord, formed the gravel bench which exists there at an elevation of about 140 feet, by planing off the morainic deposits.

For the phenomena described in this and the preceding section two possible interpretations present themselves: (1) The advancing glaciers of the great ice flood made the gravel deposits, then overrode them, but failed to remove them; (2) the recession of the great ice advance, or a recent re-advance, or both, were accompanied by gravel deposit, and the re-advance overrode a part of the gravels, but did not last long enough to completely remove them. Unfortunately, the platform on which the gravels rest was nowhere seen, so that direct evidence from this source is not available. The reason for considering the first explanation impossible is indirect, but seems to the authors convincing. It is that, if the gravels were formed in front of the ice in the main period of advance and then overridden by it, they must surely have been removed by erosion. If our conclusion that there has been profound ice-erosion in the fiords is correct, the extensive gravel deposits surely could not be left where they now stand. Some of them in Nunatak Fiord lie directly beneath the lip of a hanging valley; and others in Russell Fiord extend across the mouth of a hanging valley. Even without the assumption of such profound ice-erosion as is believed to have been accomplished in this region, it seems inconceivable that ice over 2,000 feet thick, and 25 miles from its terminus, could have passed over gravels for a long enough time to build the great Yakutat Foreland and yet not remove a series of gravels, especially in view of the scratched, grooved and plucked rock cliffs, indicating that the ice was a powerful erosive agent. The wonder is that even a brief advance of the ice, extending part way through the fiord, should have left such extensive accumulations of gravel. But this is not the only region where the evidence indicates earlier powerful glacial erosion and later weaker advance failing to remove gravel and even products of residual decay.

This evidence, though indirect, is therefore advanced as proof that the gravels were formed subsequent to the great ice advance, and that they were very recently overridden by another advance which extended part way through the fiord but did not last long enough to erode the gravels formed at an earlier stage. That the recession of the ice from these gravels, now actively in progress, is very recent is indicated by the vegetation, as stated below. Without much doubt this advance was the one which stopped the explorations of Malaspina in 1792 and Puget in 1794, when they found Disenchantment Bay blocked by ice down as far as Haenke Island.\*

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\* It is noteworthy that the succession worked out in the Yakutat Bay region is almost identical with that demonstrated for the Muir Inlet region by Wright, Reid, and Cushing.

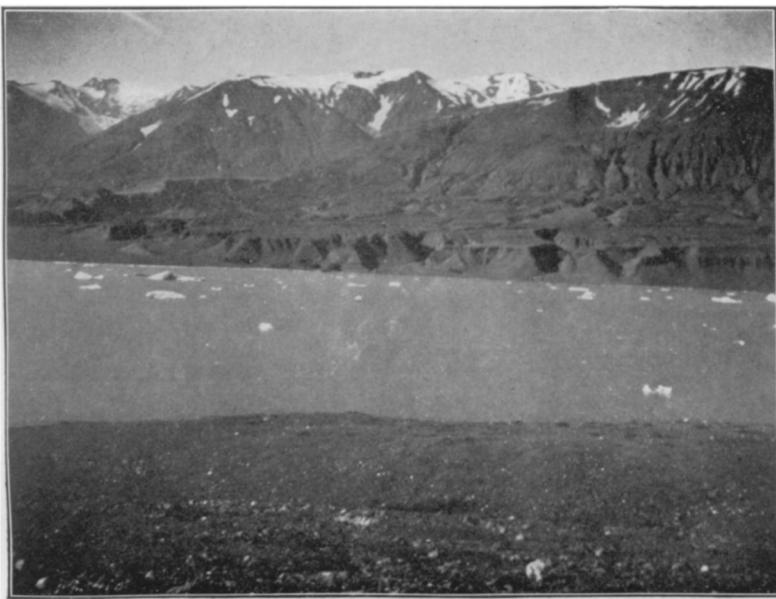


FIG. 19.—DISSECTED GRAVEL TERRACES ON THE NORTH SIDE OF NUNATAK FIORD, ABOUT TWO MILES BELOW THE SEA END OF NUNATAK GLACIER. THESE GRAVELS HAVE BEEN OVERRIDDEN BY THE ICE AND BEAR A VENEER OF MORAINE. VEGETATION HAS NOT YET OCCUPIED THEM.



FIG. 20.—SECTION IN THE OVERRIDDEN, MORAINE-VENEERED GRAVELS ON THE WEST SIDE OF THE SOUTH ARM OF RUSSELL FIORD. VIEW LOOKS SOUTHWARD AND IN THE DISTANCE SHOWS THE OVERRIDDEN GRAVEL AREA ON THE EAST SIDE OF THE FIORD, JUST NORTH OF RUSSELL COVE. (SEE ALSO FIG. 24.) ONLY SCATTERED ALDERS AND OPEN THICKETS HAVE ADVANCED THUS FAR NORTHWARD.

ADVANCING VEGETATION OF YAKUTAT BAY.—In 1892 Funston collected plants in Yakutat Bay up as far as Haenke Island; but no detailed botanical study, so far as known, has been made beyond this point. In variety of species present the region is not an inviting one, but in distribution of plants the field is most attractive; for it is a region from which the ice is even now receding, and in which one may note the advance of a flora upon a land newly opened to plant occupation by ice withdrawal. Unfortunately, none of our party was trained as a botanist, and other duties prevented the collection of plants; but some general features were so noticeable that they could not escape attention.

The Yakutat Bay region presents two entirely opposite conditions of vegetation. On the one extreme is the typical dense Alaskan forest; on the other, a desert (Figs. 16, 19, and others). The forest clothes the foreland and the lower mountain slopes at the head of Russell Fiord and on the border of Yakutat Bay. In the damp, equable climate the vegetation grows luxuriantly and the forest is dark, damp, and difficult to penetrate. It is mainly of Sitka spruce, with individuals 70 feet high. Much less abundant is the hemlock. In favourable situations the cottonwood grows, in places forming forests, with little or no spruce in it. According to Funston, the spruce rises to an altitude of 2,200 feet on the sides of Mt. Tebenkof; but the timber-line descends toward the interior, reaching sea-level in Disenchantment Bay. In the narrower Russell Fiord the forest reaches less than half way northward from the head of the inlet toward Cape Enchantment.

Between the forest and the desert there is an area occupied by alder and willow, which grow in such an intricate tangle as to make passage a most difficult task, rendered exasperating by the presence of the thorny devil's club. The same type of growth occurs on the mountain slopes above the forest zone. This alder tangle occurs in many valleys of the peninsula, along both shores of Russell Fiord just north of the forest zone, along the shores of Disenchantment Bay, and in a part of the stretch of Russell Fiord between Gilbert Point and Cape Enchantment. It is absent from Nunatak Fiord, and from most of Russell Fiord between Marble Point and Seal Bay.

The desert is in part the result of rugged mountain, snowfield, and ice conditions; in part it is caused by the presence of moraine-veneered ice with a shifting soil, and of alluvial fans now building; but over large areas the desert condition is due to the fact that ice has so recently left the land that woody plants have not found time to occupy the soil. This is especially true between Marble Point and

Seal Bay, including Nunatak Fiord (Figs. 17 and 19). Here the alder and willow have begun to grow, but, excepting in a few spots, have not succeeded in developing the characteristic, almost impenetrable thicket. Nearest to the ice of the Nunatak and Hidden Glaciers no alders or willows grow, but between the glaciers and the area of alder thickets are individuals and clusters, increasing both in size and abundance away from the ice.

There can be no question that vegetation is following up the receding ice, and that its stages of advance are here plainly recorded. The ice is receding faster than vegetation can advance, and light-seeded alders and willows have pushed farthest forward. That the forest trees have not advanced as far as is possible under existing climatic conditions, and that the forest is now marching toward and into the desert area, is indicated by a number of facts. In the first place, the climate is apparently favourable. We have not climatic data to prove this beyond question; but the summer from the first of July to the first of September is certainly favourable; and, even with the neighbourhood of glaciers and snow-clad mountains, it seems improbable that the winter cold here can be too severe for trees, for the area is near the warm ocean, open to its influence, and is bathed by fiord waters. In the second place, the limit of tree growth is not marked by stunted trees, as is the upper limit of tree growth on the mountains. Well-formed and good-sized spruces and cottonwoods mark the northern limit of the forest, which could hardly be the case with a forest limited by adverse conditions. Furthermore, the light-seeded cottonwood is in advance of the heavy-seeded spruce. Finally, both spruce and cottonwood in scattered individuals occur well in advance of the forest. Scattered young cottonwoods occur within a few miles of the present terminus of the Nunatak Glacier, and there are two or three young spruces, estimated to be fifteen or twenty years old, growing on Haenke Island. Funston in 1892 reported that there were no spruces in Disenchantment Bay; but in 1905 there certainly were several spruces as far up this bay as Haenke Island.

There is in this bay a splendid chance for an interesting ecological study; and it ought to be made now, for purposes of comparison at some future time. Not only is there this general problem, but also the very interesting phenomenon of the growth of vegetation on the moraines of living ice.

THE FAUNA OF YAKUTAT BAY.—No attempt was made to study the fauna of the region, and it is not the purpose here to give a list of even those animals observed, but merely to point out the evidence



FIG. 21.—FOREST BURIED IN CLAY BED IN GRAVELS, NEAR SOUTH END OF RUSSELL FJORD. THE HEAD OF THE BAY IN THE DISTANCE, WITH STRAWBERRY ISLAND ON THE RIGHT. THE MAN STANDS NEAR ONE OF THE BURIED TREES. VIEW LOOKS SOUTHWARD.

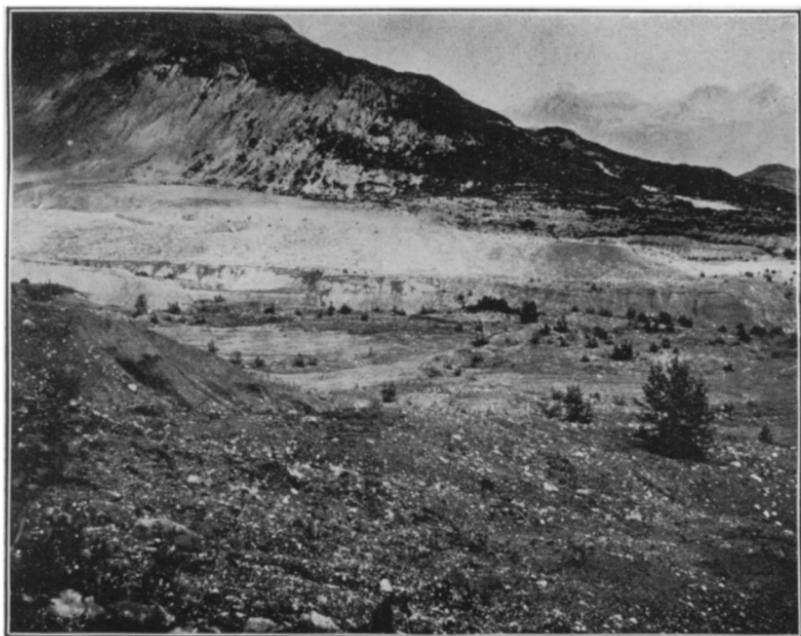


FIG. 22.—LOOKING NORTHWARD ALONG WEST SIDE OF SOUTH ARM OF RUSSELL FJORD, JUST SOUTH OF CAPE ENCHANTMENT. OVERRIDDEN, MORAINE-VENEERED GRAVELS FORM THE FOREGROUND AND THE RIGHT MARGIN OF THE PICTURE. THE GRAVELS ARE REVEALED IN A STREAM CUT IN THE MIDGROUND, AND BACK OF IT IS MORAINE-VENEERED ICE (LIGHT-COLORED), RESTING ON THE GRAVELS. VEGETATION HAS ONLY BEGUN TO REOCCUPY THIS OVERRIDDEN AREA.



FIG. 23.—SMALL ESKER ON THE RIGHT AND EXTENDING UP TO THE MAN AND THENCE SWINGING TO THE LEFT; RESTING ON THE OVERRIDDEN GRAVELS (FIG. 19) ON NORTH SIDE OF NUNATAK FIORD.



FIG. 24.—LOOKING SOUTHWARD UP THE SOUTH ARM OF RUSSELL FIORD ON THE WEST SIDE. THE OVERRIDDEN GRAVELS NEAR RUSSELL COVE SHOW ON THE LEFT. THE FOREGROUND SHOWS MORAINE OF RECENT ICE ADVANCE. AN ALDER THICKET HAS ADVANCED THUS FAR NORTHWARD, OCCUPYING THE AREA FROM WHICH ICE HAS RETREATED. SOUTH OF THIS THE ALDER GROWTH BECOMES MORE EXTENSIVE, THE REGION HAVING BEEN LONGER FREED FROM ICE.

that the fauna, as well as the flora, has not yet advanced to occupy the regions recently ice-covered. It would be most interesting if this statement could be extended to include the marine life as well, which would doubtless show similar conditions.

One fact of general interest is that the deer, abundant farther south—around Sitka, for example—have not passed the ice barriers and migrated to the Yakutat Foreland, where conditions for their existence are most favourable. The mountain sheep, black and brown bear, wolf, fox, marmot, and some smaller mammals do, however, occupy the region.

Within the area of the Yakutat Bay region itself there is proof of the effectiveness of the ice barrier to the progress of mammals. Puget Peninsula abounds in foxes, and wolves; and both here and on the mainland to the east and west, black and brown bear are abundant. None of these animals were seen in the region between the Nunatak and Hubbard Glaciers; nor were their tracks, very abundant elsewhere, seen there. In harmony with this scarcity, and apparent complete absence, of these mammals from that particular area are two facts pointing to the conclusion that they have not occupied this section. In the first place ptarmigan, which are an easy prey to carnivorous animals, are exceedingly abundant there; in fact we called this the Ptarmigan Coast, and to it sent our natives whenever we wanted a supply of these birds. In the second place, the gulls nest on the ground on the moraine of the Variegated Glacier, while elsewhere in the inlet they build nests on the cliffs in places as nearly inaccessible to foxes as possible.

The extensive ice area of the Nunatak and Hubbard Glaciers, which are badly crevassed, the lofty intervening snow-capped mountains, and the water barrier of the fiord seem to have acted as effectual barriers to the spread of carnivorous mammals to this shore of Russell Fiord. But even these barriers, as at present existing, could hardly have been completely effective for a long time; and the evidence from other directions proves that the ice barrier is now of far less importance than formerly, and that, with its partial removal by recession of the glaciers, the area of unoccupied land has been recently greatly increased.\*

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\* As at first written this article was prefaced by a general description of the region and a review of the literature; but it became necessary to omit this portion. This is the explanation of the failure to refer more specifically to Russell's splendid pioneer work and to his papers—*Nat. Geog. Mag.*, Vol. III, 1891, pp. 53-203; 13th Ann. Rept. U. S. Geol. Survey, 1891-2, Part II, pp. 1-91—to which we are greatly indebted. Reference should also be made to Frederick Funston's paper—*Contributions from the U. S. National Herbarium*, Vol. III, No. 6, 1895, U. S. Dept. Agriculture.